

## **Neurovestibular Effects of Long-Duration Spaceflight: A Summary of Mir-Phase 1 Experiences**

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**Abstract**

Space motion sickness and associated neurovestibular dysfunction – though not completely understood - have been relatively well clinically and operationally characterized on short-duration (1-2 week) Space Shuttle missions (Oman, et al, 1984, 1986; Thornton, et al, 1987; Reschke, et al, 1994). Between March 1995 and June 1998, seven NASA astronauts flew on the Russian Mir space station, as “Phase 1” of the joint effort to build the International Space Station, and provided NASA with invaluable experience on the operational and biomedical problems associated with flights of up to six months in duration. The goal of this paper is to provide a summary of the available information on neurovestibular dysfunction, space motion sickness, and readaptation to Earth’s gravity on the NASA Mir flights, based on a set of medical questionnaire data, transcripts, and interviews which are available from the NASA-Mir Phase I program. Records were incomplete and anecdotal. All references to specific crewmembers have been removed, to respect their individual privacy. Material was excerpted from multiple sources of information relating to neurologic function, sensory illusions and motion sickness of NASA-Mir Phase 1 Program crewmembers. Data were compiled by epoch (in-flight vs landing/postflight) and grouped by neurovestibular topic. The information was recorded either contemporaneously during or within days after landing, or retrospectively weeks to months later. Space motion sickness symptoms are more intense and longer in duration. Sense of spatial orientation takes at least a month to become “natural and instinctive” in space station structures, but mental survey knowledge is apparently not completely developed even after 3 months in some cases. Visual reorientation illusions (VRI) are more easily induced after long exposure to weightlessness. Head movements can cause illusory spinning sensations for up to 7 days postflight. Postural and balance control does not fully recover for at least a month postflight. It



is clear that long duration Mir crewmembers experienced neurovestibular dysfunction that was usually more intense and longer in duration than on shorter flights. The differences appear associated to mission duration and vehicle size and architectural complexity. That postflight disorientation and ataxia increase with mission duration suggests that there are some components of sensory-motor adaptation to weightlessness that occur over timescales far longer than the 1-2 weeks previously assumed. Current methods for evaluating inflight neurovestibular function produce only qualitative data, which limits statistical analysis, and consequently, its utility in determining the effects of long-term exposure to microgravity.

## **1. INTRODUCTION**

Space motion sickness and associated neurovestibular dysfunction – though not completely understood - have been relatively well clinically and operationally characterized on short-duration (1-2 week) Space Shuttle missions [13,14,18,23]. Between March 1995 and June 1998, seven NASA astronauts flew on the Russian Mir space station, as “Phase 1” of the joint effort to build the International Space Station, and provided NASA with invaluable experience on the operational and biomedical problems associated with flights of up to six months in duration. The goal of this paper is to provide a summary of the available information on neurovestibular dysfunction, space motion sickness, and readaptation to Earth’s gravity on the NASA Mir flights, based on a set of medical questionnaire data, transcripts, and interviews which are available from the NASA-Mir Phase I program. Although the records are incomplete and anecdotal (see Table 2.1), this information is important for planning operations and research aboard the International Space Station. The available information provided by the Mir crewmembers was edited, when possible in narrative form so the story is told in their own words. The relevant postflight clinical

notes and neurologic function exams were tabulated and all references to specific crewmembers have been removed, to respect their individual privacy.

Human locomotion, postural control, eye-head coordination, and spatial orientation depend on the appropriate integration of inputs from the visual, vestibular, proprioceptive, and tactile systems by the central nervous system (CNS). When astronauts enter orbit, signals from the otolith organs of the vestibular system and other body gravireceptors are no longer in congruence with those from other receptors due to the absence of gravity. The CNS adapts to this incongruence, however, and learns to integrate the sensory signals without the usual gravitational input. One explanation of how this happens is the otolith tilt-translation reinterpretation (OTTR) hypothesis [17,25], which suggests that the brain learns to interpret changes in graviceptor output as linear acceleration. Upon return to Earth, head tilt causes illusory translation. Until adaptation to weightlessness (or readaptation to Earth's gravity) is complete, inappropriate signal interpretation causes sensory conflict and triggers space motion sickness (SMS) and a collection of other symptoms related to 0-G fluid shift often referred to as Space Adaptation Syndrome (SAS). The corresponding postflight nausea syndrome has been called "Earth Sickness" [14], and the entire postflight symptom constellation is often called "Spaceflight Re-adaptation Syndrome".

On short-duration flights, SMS symptoms and signs resemble those of terrestrial motion sickness, superimposed on discomforts associated with 0-g fluid shift. Both on Earth and in space, motion sickness symptoms typically include pallor, sensation of warmth, cold sweating, dizziness, drowsiness, yawning, flatulence, headache, epigastric awareness, nausea, vomiting,



fluid shift discomforts, "wet burps," and other symptoms including anorexia, lack of motivation, and irritability [6]. Anecdotal data also suggest crewmembers experience impaired concentration and problems with short-term memory. Symptom patterns vary, and some crewmembers never vomit, but some symptoms are reported by three-quarters of all crewmembers on the US Shuttle. Symptoms can appear as early as immediately after reaching orbit, and most typically resolve after 30 to 48 hours (reported range 12 to 72 hours). This time scale, however, was derived from observations made on short-duration missions. Rate of recovery, degree of adaptation, and specific symptoms vary widely between individual astronauts. Large amplitude head and body movements appear to be the dominant stimuli. Mercury and Gemini astronauts reported no SMS symptoms most likely because they flew in small capsules that minimized movement of the head and body. Some crewmembers have reported particular head movements to be more provocative than others (e.g., pitch).

Inversion illusions and visual reorientation illusions (VRIs) are inflight disturbances known to provoke SAS symptoms. Inversion illusions ("hanging upside down") are common during the early days, and can persist with eyes open or closed for minutes to hours. Crewmembers also frequently report VRIs, which are characterized by a perceptual change in one's spatial orientation relative to an environment. The 1-g version of a VRI usually involves reorientation about the gravitational vertical, such as when a person emerges from a subway facing an unexpected direction. In microgravity, however, VRIs most often involve illusory reorientation orthogonal to the subjective vertical. The most commonly reported in-flight VRI, sometimes called "the downs," is the perception that, whichever direction a crewmember's feet are pointing is considered a "floor." This illusion can be triggered when viewing another crewmember



floating upside down (Is the floor beneath his feet or mine?). Many Shuttle astronauts prefer to remain visually upright in the spacecraft whenever they are symptomatic. This helps minimize orientation confusion and any SMS symptoms that would otherwise hamper performance. Other in-flight neurovestibular phenomena include proprioceptive illusions, such as illusory movement of a surface when pushed against. A few crewmembers have reported motion of the visual environment (oscillopsia) during passive or voluntary head movements, though the effect is usually small. The sensation of not knowing the position of limbs with respect to the trunk when muscles are relaxed has also been described.

During re-entry, landing, and for hours-to-days post-flight, most crewmembers experience head movement contingent oscillopsia and self-movement illusions, much more dramatic than any illusions encountered on-orbit. These perceptual illusions are usually strongest during re-entry and in the first minutes after wheelstop. Crewmembers usually experience disturbances of more than one category at a time. Proprioceptive illusions are also common: crewmembers feel as if the floor is moving up and down under them while walking.

Flight surgeons and researchers often use the term “neurovestibular dysfunction” when referring to the sensory illusions, motor deficits, and motion sickness associated with spaceflight. It is important to emphasize that so far there is no conclusive scientific evidence that these dysfunctions are associated with specific pathophysiological changes in the vestibular end organs or CNS. Rather, they seem to be the consequence of sensory-motor adaptation to an abnormal gravito-inertial environment.



## **2. METHOD**

Multiple sources of information relating to neurologic function, sensory illusions and motion sickness of NASA-Mir Phase 1 Program crewmembers were identified, and are cited in the references. The material was excerpted, and is presented in the Results section, compiled by epoch (in-flight vs landing/postflight) and grouped by topic. Quotations are used whenever possible and appropriate. Text [in brackets] has been added to provide context or improve clarity. Information from other sources is not surrounded by quotation marks. In order to preserve anonymity, names of individual crewmembers have been edited out. Instead, individuals are referred to simply as “crewmember” or in tables by using an arbitrarily assigned letter or number. Quotations and references that imply gender have been arbitrarily converted to the masculine form. Except for publicly available material, references with dates tied to specific missions were not cited in the text. Pre-flight (L-) and post-flight (R+) dates are designated according to number of days prior to launch and after landing, respectively. For example, R+0 is landing day.

### **2.1 Medical Debrief and Questionnaire**

The information was recorded either contemporaneously during or within days after landing, or retrospectively weeks to months later. Contemporaneous data included Flight Surgeon R+0 notes, Debrief Questionnaire, and Debrief Transcripts for some crewmembers as shown in Table 2.1. Clinical notes were routinely made by the flight surgeon [7] pertaining to the condition of the crewmembers upon egress from Shuttle (e.g., Did they walk away from the shuttle or were they carried out?). Observations of re-adaptation syndrome symptoms and signs were made. Flight surgeons also conducted a routine postflight medical questionnaire [21] for NASA

crewmembers returning from MIR both on R+0 and R+3. The R+0 questionnaire asked crewmembers to review a list of SMS and neurovestibular symptoms, and to judge their presence/absence and severity by flight day and time of onset. Crewmembers were asked to indicate what activities/factors made symptoms worse or better. They were also asked to indicate which SMS medications they used and how effective they seemed to be in relieving symptoms. The form also asked several open-ended questions regarding shuttle orbiter emergency egress ability. The R+3 questionnaire asked what symptoms they had experienced since their R+0 report, how long the symptoms lasted, how severe they were, and whether they were still present. Open-ended questions regarding what made symptoms worse or better were also asked.

<<Table 2.1 should go about here>>

## **2.2 Neurologic Function Exam**

NASA's flight medicine department developed a flight surgeon's checklist for systematically administering and recording 11 simple postflight tests and observations of neurological function. Crewmembers' subjective ratings of symptom intensity and flight surgeons' objective observations of motor performance and posture control were recorded based on a 4-point scale [1 (normal functioning) to 4 (severe effects)]. The assessment was completed for most crewmembers on days L-10, L-3, R+0, and R+3 and occasionally on other opportunities (e.g., R+30 or R+145). A composite score was tabulated as the sum of the scores of individual items and reflected 3 levels of functioning: "normal" (11-13), "suspect" (14-15), and "consider referral to neuroscience lab for posturography, gaze, and locomotion tests" (>15).



## **2.3 Science Reports and Historical Accounts**

Conclusions about pre- and post-flight data on eye-head coordination, locomotion, and postural equilibrium control collected by scientists in the Neurosciences Laboratory at JSC were released in a series of research reports [2, 16, 18]. Preliminary findings were reported for both astronauts and cosmonauts. A summary [15] of medical lessons learned, that included preflight and postflight posturography results and conclusions about neurologic function and fitness for return to duty was also produced. Several crewmembers were informally interviewed post-flight by flight surgeons and neurovestibular experts. Notes were made at the time of the interview, but, in certain cases, the interviews were conducted several years postflight. Interviews were also conducted by a NASA contractor and included first-hand accounts of several of the MIR crewmembers' in-flight and post-flight neurovestibular experiences [10]. Other historical accounts of crewmembers' experiences on MIR were in publicly available books and television series [1, 3, 9].

## **3. RESULTS**

### **3.1. ADAPTATION TO 0-G**

#### **3.1.1 Space Motion Sickness (SMS)**

Two of the seven U.S. crewmembers reported one or more episodes of vomiting during inflight operations. One crewmember recalled his symptoms began 1 min. after the onset of weightlessness and lasted for 60 min. SMS symptoms were made worse by head or body movement (axes not specified), sensory conflicts, hot ambient temperature, and workload during which the head was moving. Vomiting, holding his head still, and generally less movement

helped to minimize symptoms. Another crewmember said that “uphill” [i.e. launch and the first day in orbit] was easier than on a previous shuttle mission. He’d had a day of sickness on the shuttle mission before that and no symptoms after 5 days. The following comments were made by a crewmember regarding his SMS experiences:

“One thing I found out ... as a sufferer of space motion sickness [is that] ... there is absolutely no question that [head movement] is what causes and exacerbates [it].”

“... once you get over [SMS], it doesn’t come back.”

“... about six hours into the mission, like I always did, I started getting symptoms.”

[referring to an earlier Shuttle flight]

A second crewmember said:

“Two of the three new arrivees expressed no interest in eating.... Their faces looked pale; they flew tentatively, trying to move as little as possible and always with their feet ‘down’... it was also obvious that the voluminous Mir nauseated them.”

“... the one having the most problems is [a new arrival]. He has already started vomiting... [10 days later] he has had a tough time adapting to his first spaceflight. From his first hours in orbit [he] has been vomiting more or less constantly. He is nauseous for long periods every day...”

### **3.1.2 In-flight pharmacological treatment of motion sickness**

One crewmember said:

“I had not had much luck with scope-dex. It would always protect me for a day or two, but ... after [that], it would no longer protect, ... it would just mean I’d be sick on the second or third day.” [Referring to his previous experience treating SMS with scopolamine-dexedrine on shuttle flights]



“... I took a [12.5 mg dose of intravenous phenergan], and the symptoms within five minutes were just gone, totally. I mean, it was a cure.... a few hours later, when the symptoms started coming back again, I took another 12.5 mg and the symptoms went away.... About twenty hours into the flight, ... [I took about] twenty [mg of phenergan before going to sleep].... when I woke up, ... I didn't have any symptoms and never had any symptoms after that.”

### **3.1.3 Spatial disorientation and spatial memory problems**

Several crewmembers reported difficulties with spatial orientation inside Mir, and problems inter-relating the coordinate frames of adjacent modules, which occasionally caused significant operational problems. Mir module interiors had brown floors, tan walls, and light colored ceilings. Several crewmembers noted maintaining spatial orientation visually within a module was relatively easy provided one remained in the familiar visually upright position. However, modules were connected at right angles to each other at a central hub (the “node”) and their visual verticals were not co-aligned. The Priroda module verticals were oppositely aligned from those in the base block, so crewmembers moving between the modules learned to turn upside down when moving between these two modules. Occasionally, it was more practical to work in a visually inverted position inside.

According to one crewmember, it was confusing in the first few days on board. The place seemed much bigger than he expected. He noticed that when people from the Shuttle arrived on Mir to pick him up, they seemed lost. With respect to spatial orientation, it took about a month till finding one's way around seemed natural and instinctive. Ground trainers weren't helpful, since they aren't in the real relative orientations, and can't be re-oriented. But after about four



weeks of living onboard Mir, one learned to come out of a module, automatically do a 90-degree rotation if needed, and zoom into the next module without much thinking about it, even though the floor and ceiling were in different orientations. Even by the end of the flight, this crewmember had no mental survey knowledge that included all the modules. He said he could not have pointed to places in the other modules from base block, or vice versa. He never did get the big picture from inside and felt he had a better understanding of Mir from the outside in. He tried to memorize what was inside each module, as seen from the outside. But it was another thing to visualize one module from inside another, and for some reason he couldn't do it. Another crewmember remembered that when working upside down, he deliberately initiated a VRI in order to feel right side up again. He found it easier to do this as the mission went on. He remembers noticing that after awhile, when he went upside down, he didn't have to wait till his feet got near the floor before the ceiling became down. VRI onset occurred even before his body had turned 90 degrees.

The majority of Shuttle, MIR, and Skylab crewmembers claim to depend heavily on visual cues for orientation and consider these cues very important when confusion occurs. MIR crewmembers reported that navigation is especially difficult when passing through the node. Spatial orientation difficulties encountered in the node prompted Russian cosmonauts to place red arrows made of velcro on the walls pointing toward the Shuttle adapter hatch for the convenience of Shuttle visitors, thus creating their own emergency escape markings.



When interviewed post-flight, another crewmember made the following comments regarding spatial orientation, orientation preferences while working, and difficulties interrelating the coordinate systems of adjacent modules:

Interviewer: "If you anchor yourself, for example, on the treadmill, can you imagine where the far end of the Spektr module would be?"

Crewmember: "The treadmill gives you perspective into the node. And you can see the cap on the ... module, ... so you know Spektr's that way. You see the hatch from the Soyuz, you know the Soyuz is ... straight across. You know it's there, and you know up. Straight up. So that's the way you learn it. We generally maintain up-down orientation always."

Interviewer: "On waking or when it was dark, did you try to navigate?"

Crewmember: I did, at times, lose orientation particularly in the early days, when I had to make a right angle turn from Priroda into the base block.... You not only have to turn, you have to roll like, ... I don't even remember it. Sometimes ... you have to roll and after a while you learn which way you had to turn instinctively. But, even after last week when I was up there, ... I stopped at the node to look to see where the [other modules] were. So [I would] have to look 90 degrees, and in that process ... come around, ... stop, ... change [my] orientation a little bit, and I wouldn't remember which direction I was going and ... have to re-orient and say, 'ok where's the landmark?' I know there was a red stripe on Kristall. I looked at the color of Priroda – blue. That happened a lot.... you just stop to take a moment to look at something, and you come back to the way you thought you were heading, and ... you would forget which way it was. You'd have to look around to find where...things were."

Interviewer: “[Another crewmember] described it as living in a ranch house and not knowing in his mind when he was in one particular location, nor could he really decide at that point where things were located.”

Crewmember: “And that’s true. You don’t have a good sense of it because it’s not planar.

After a while, I learned ... Priroda and Kristall and base block are in a plane, but ... the modules aren’t on the same floor plane, and I would have to go through and I’d have to turn, but I could never remember which way I would turn. Well, I guess to turn clockwise 90 degrees, you have to know the layout of the module. But every time I went from base block, [I would] do a left turn, and then ... roll [my body] to get the orientation to the floor. Because base block floor is like this, but Priroda’s floor is like this, or it was like this. I can’t remember if it’s on the near side or the far side.”

Interviewer: “So, regardless if the floors were 90 degrees, you always kept to the floor?”

Crewmember: “That’s right, we always used the floor as the flooring even if the floor was actually the ceiling to one of the other modules or a wall. And that worked out well. The floor of Priroda and the floor of Kristall were the same.... [Going from Priroda to Kvant] used to always throw me, because Priroda’s floor was [not aligned with] Kvant’s. ... I can’t even remember... I used to know that instinctively. [Upon entering] Kvant, ... I would instinctively turn to what I thought was the right orientation, to turn 90 degrees, and I’d usually end up going to turn too suddenly, because I can’t remember the way. You’d have to look around and find a reference and reorient yourself....”

There were at least two instances in which Mir crewmembers had problems visually locating a Progress supply ship arriving to dock. Accounts of these events say that Mir’s solar arrays prevented onboard observers from visually locating the arriving ship. Russian and US



neurovestibular experts, however, believe that the problems were due to difficulties crewmembers had mentally visualizing the orientations of the spatial coordinate frames of the different modules relative to one another. Three-dimensional mental rotation and visualization of an environment is an unfamiliar and difficult mental challenge for most humans. Unfamiliarity with such challenging mental tasks likely also made it difficult for crewmembers to instinctively know which window one should be looking out after moving between modules. Some crewmembers feel this is an intellectual problem, not a neurovestibular one. The difficulty of knowing where the Earth, moon and horizon are during an inertial rendezvous is a significant intellectual problem and depends on the crewmember's knowledge of different reference frames, the station's orientation and geometry and their depth of understanding of orbital mechanics. This task becomes even more challenging when factoring in the trajectory of an approaching spacecraft. During the first docking attempt, one crewmember describes the crew as moving from one window to another in an attempt to find the incoming Progress. He was in the far end of Kristall, while his crewmember was serving as a second pair of eyes, moving between windows in base block and Kvant. The following is that crewmember's account of the experience:

“[Crewmember 1] would pick his spot according to where he could best see the incoming Progress - something that none of us could predict with any confidence.... [Crewmember 1] and I [looked] for the approaching spacecraft.... Though I was moving from one Mir window to another, I could still not see the approaching spacecraft.... [Crewmember 2] was flying frantically back and forth between his control station and the nearest porthole-sized window on the floor. [Crewmember 1] was crouched down at this same window, shouting [directions] to [Crewmember 2].... I flew to a window that faced the same

general direction as the window [the other crewmembers] were using and did so just in time to see the Progress go screaming by us... [3]

Later, after an unsuccessful attempt to manually dock the incoming Progress:

“The only way [Crewmember 2] could determine whether he had done the right thing was by yelling to [Crewmember 1].... For [Crewmember 1], accurate description [of the movement of Progress] was an impossible task. Describing an object that was flying in three-dimensional space and calculating the closing speed of that object without a relative reference point cannot be done impromptu. Without a reference point, "right", "left", "up" or "down" are words without meaning.”

One docking attempt resulted in a collision with the Mir station, depressurizing the Spektr module, and turning Mir's solar panels away from the sun, resulting in a critical loss of power. To get the solar panels pointed back at the sun, and to restore power to the station, two of the crew attempted to use the Soyuz's thrusters to control the orientation of the disabled Mir station they were docked to, based on verbal commands from the third crewmember who was looking at attitude instruments in the Mir base block. This required the crewmember in the base block to mentally visualize the orientation of the crew in the differently oriented Soyuz cockpit, which proved quite difficult.

One crewmember's account :

“It was horribly complicated because the Soyuz control axes were controlled by 45 degrees to the station axes, so we had a very, very confusing technical dialogue... [The crewmember] and I were both confused for at least an hour as to quite how the axes of the Soyuz lined up with the rest of the station. We had no clear picture. There was no picture in our flight files. The [onboard physical] model [of Soyuz/Mir] wasn't correct.”



“As you fly through the base block into the Soyuz, the node, ... you have to do a twist around the hatches, and that twist totally throws off your orientation.... So we had a running argument as to what that orientation difference was. We knew it was 45 degrees out; we didn't know which way.”

The ability to instinctively make three-dimensional spatial judgements is also important if emergency evacuation is necessary in darkness, or if smoke obscures the cabin. On one occasion, an oxygen canister caught fire. One crewmember recalled:

“By now, smoke was rapidly filling up the entire space station. It was so invasive that, in the few seconds that I peered down the tunnel, visibility was reduced within the base block module to near zero... Flying blindly through the smoke, more by familiarity than by sight, I accidentally bumped into a platform holding a laptop computer.” [9]

### **3.1.4 Height awareness and sensations of falling**

One space-walking crewmember described an episode [9] of intense height awareness, reminiscent of the acrophobia-like height vertigo that many people experience on Earth when compelled to stand without a guardrail at the edge of a high precipice:

“... nothing had prepared me for the terror that came over me when dangling from the end of a telescoping pole outside the confines of the space station during my spacewalk.”

“I was dangling on the end of a wavering pole, getting pushed out farther and farther from the space station. ... Suddenly, it hit me: the feeling of speed ... faster than anything that I ... had ever experienced in my life. Accompanying this overpowering sense of speed was the overwhelming sensation of falling. I felt as if I were falling off the station and catapulting toward the earth. Furthermore, ... it felt as if the space station itself were plummeting earthward with me clinging to its surface... I wanted to close my eyes in an



effort to escape this dreadful and persistent sensation of falling. ... I reasoned that this instantaneous sense and surge of orbital speed occurred because I had lost the stabilizing visual perspective provided by the protective interior walls of the space station. ... deprived from any strong visual clues of containment, I felt as if I were falling off a cliff that just kept falling away from me. ... I tried concentrating on the surface of the station far in front of me, attempting to use visual input to mask the reality.... Despite my efforts to block the reality out, speed and falling persisted.”

“To my knowledge, this sensation of falling rarely occurs during shuttle spacewalks, probably for two reasons. First, and probably most important, almost all shuttle spacewalks are conducted within the three-wall confines of the shuttle’s payload bay. The concave surface surrounding the spacewalker is probably sufficient to maintain the illusion of being contained, of being surrounded by a stable frame of visual reference. Second, whenever the spacewalker moves out of this envelope of containment, he or she is usually firmly attached by footholds to either the end of the robotic arm or to the edge of the payload bay. As I found on Mir, whenever I was able to wiggle my bulky, boot-laden toes under a handrail, the stability provided lessened the sensation of falling.”

“My friend admitted to me that ... he, too, had experienced the same frightening phenomenon. Feet securely in place on the robotic arm, he was being conveyed to the far end of the [satellite]..., well out in the confines of the payload bay. ... in order to begin his repair work, he had to extricate himself from the stabilizing foot-loops and cross over to the [satellite]. Feet now free and reaching across the two-foot gap to the end of the [satellite], he unexpectedly and overwhelmingly felt the sensation of falling off the edge



of the world! Stunned by the unexpected sensation, he bear-hugged the convex surface ... and hung on for dear life! Once he was stabilized on the end of the [telescopic arm], the sensation eased and he was able to continue working. His space-walking partner experienced the same phenomenon at precisely the same location. His reaction was the same: to cling on to the [satellite].”

Another crewmember performed an EVA on Mir without experiencing height vertigo, but he was aware of the potential problem, and was careful to hold onto the Mir with one hand and concentrated on using it as a frame of reference. He noted that when training in neutral buoyancy tanks on the ground, he made a point of not paying attention to the pool walls and always used the vehicle for reference. He believes holding on to and looking at the vehicle may be a useful countermeasure against height vertigo.

In postflight interviews, at least one crewmember noted it was possible to cognitively induce an illusory falling sensation while inside the Mir:

Crewmember: “... I know other astronauts have talked about this.... I could just stop myself and close my eyes, and think that I was falling backwards.... Sometimes [it would] happen when I was sleeping or taking a nap.... And you open your eyes and [feel] absolutely stationary, and then you can ... close them again and ... can get the same feeling that you’re falling in the other direction [just by concentrating on it]. Although, [the illusory motion] tends to be like falling backwards.”

### 3.2 RE-ADAPTATION TO 1-G

On returning to Earth from long-duration space flight, crewmembers experienced many of the same neurovestibular symptoms as their short-duration counterparts, only with more intensity. There is an even stronger sense of heaviness, sometimes to the point of complete incapacitation. Increased feelings of nausea and vomiting were common and exacerbated by spinning and pitching sensations induced by head movements. Four of the seven U.S. astronauts reported one or more episodes of vomiting postflight, two different crewmembers reported vomiting inflight but not postflight (see Table 3.1). One crewmember reported having no episodes of inflight or postflight vomiting. As expected, some symptoms occur on landing day during re-entry and after wheelstop. Long-duration crewmembers, however, experience some symptoms lasting several days and sometimes months post-flight. Neurovestibular symptoms experienced after wheelstop are described below in the crewmembers' own words when possible and organized according to the time at which the reports were made (i.e. on R+0, between R+1 and R+7, and after R+7).

<<Table 3.1 should go about here>>

An increased sensitivity to *g* forces is the most frequently reported symptom during re-entry into the earth's atmosphere. One crewmember made the following comment about the contrast between short-duration and long-duration flight during re-entry:

"I remember on my first flight ... telling ... our commander that he could quit pulling all those *G*s any time he wanted to, and he said, "Well, we're pulling about a tenth of a *G* right now," and that [flight was less than 10 days long]. But, after [more than 100] days, it was that feeling only even more pronounced. I felt very heavy. Other cosmonauts told me of crewmembers who vomited throughout re-entry and were essentially incapacitated even before the capsule parachute opened."



Another crewmember experienced g-related symptoms during re-entry including heart palpitations (sometime during entry interface) and neurovestibular problems.

### **3.2.1 Postflight neurovestibular disturbances: R+0**

Four crewmembers' subjective ratings of symptom severity were obtained on R+0 and are shown in Table 3.2.

<<Table 3.2 should go about here>>

#### 3.2.1.1 Increased sensitivity to g-forces

One crewmember made the following two comments about whether he thought Shuttle egress was possible after returning from Mir:

"I think I would've been able to, but it would have been tough, because ... I didn't stand up with a parachute. I've been told all that gear with a parachute is almost 90 pounds, and you've got enough trouble just with yourself, let alone a lot of gear.... I probably could have [bailed out], but I would have been really stressed and strained to do so.... I felt a little awkward, more so than on my shorter Shuttle flights."

For another crewmember, the following time clicks and observations were recorded by the flight surgeon on R+0: [Time is expressed in hours and minutes (hh:mm)]

Wheelstop+00:25 [The crewmember is] lying recumbent with head against airlock hatch, feet in locker. Looking

somewhat uncomfortable, apparently having some gas pains in lower abdomen.

+00:28 Now semi-recumbent, head propped up toward starboard side; looking more comfortable

+00:37 [The crewmember] has been standing for 40 seconds, leaning back on middeck lockers

+00:38 [The crewmember] ... remains standing... Obvious difficulty holding head upright using postural neck muscles

+00:43 [Crewmember] walking toward hatch with assist of 2 inside Fire Crash and Rescue (FCR) personnel

+00:44 [Crewmember] egressing orbiter by sitting on hatch, lying back and being caught by 2 FCR personnel waiting on outside. Stood for about 45 sec in white room with assist.

+00:45 Turning to walk with assist from white room to Crew Transfer Vehicle (CTV), holding things [along the way].

+00:50 [Crewmember] sitting in recliner, desuited operations beginning.

+00:57 Desuited, in Liquid Cooling Garment (LCG), looking very relaxed, seated in recliner with legs down.

+01:00 Still in LCG, standing without assist, no limiting neurovestibular problems

+01:18 [Crewmember] lying on gurney with back propped up about 40 degrees, noting that it's uncomfortable to lie down flat.

Crewmember could not have performed emergency egress without assistance through either the side hatch or the overhead hatch because of neurovestibular symptoms.



Crewmember was not able to ambulate without assistance. Crewmember stayed in CTV as planned (did NOT do walk-around). Mode of egress to BDCF: Used stretcher as part of protocol.

A third crewmember was convinced that in an emergency, he simply could not have bailed out or escaped from the Shuttle had it been necessary immediately after landing. Further, despite all the in-flight exercise and pre-entry fluid loading, he felt he wasn't ready for the g-forces when he returned. He felt [very heavy].

A fourth crewmember described the sensation as feeling "so heavy that there was no way I could move." This crewmember went on to say that he felt like he weighed a thousand pounds and was stuck to the deck. "I could not even lift my arm, let alone stand up and walk. No way." He believes he would have had his usual post-flight neurovestibular symptoms, but his almost complete inability to move masked them. This crewmember could not have egressed from the orbiter without assistance. He first tried to stand up 15 min. after wheelstop with his g-suit inflated to 2 clicks and was unable to move. He tried to stand again with assistance 45 min. after wheelstop, lasted 20 sec., and was feeling lightheaded.

A fifth crewmember first tried to stand up 29 min. after wheelstop with g-suit inflated to 1 click and did not have to sit back down immediately. This crewmember deflated the g-suit 34 min. after wheelstop, and consequently felt lightheaded and was nauseous. He thinks he could have egressed through the side hatch without assistance, but not through the overhead hatch. This crewmember described his landing day experience in the following manner:

"I feel heavy, as if [my flight surgeon] was sitting on my shoulders, somewhat weak, but capable ... It took tremendous determination for me to stand erect and to walk off [the shuttle]. ... [it] was a struggle against the force of gravity for me.... feeling unstable, and ... my body felt like a five-hundred-pound barbell ... I am sure that my stride resembles a shuffle more than a walk." [9]

A sixth crewmember deflated his g-suit 19 min. after wheelstop and first tried to stand up 1 min. later. He did not have to sit back down immediately and had no orthostatic symptoms. Forty minutes after wheelstop (after egressing the orbiter), this crewmember removed the g-suit in the crew transport vehicle (CTV) and used the liquid cooling garment (LCG) at its lowest setting. He felt that it would have been difficult to egress through the side hatch without assistance, but that he could have done it. But, he felt "too heavy" in gravity to egress through the overhead hatch without assistance and needed assistance in order to walk to the baseline data collection facility (BDCF).

A seventh crewmember attempted to first stand up 40 min. after wheelstop and had to sit back down immediately. He deflated the g-suit in the CTV 60 min. after wheelstop and did not experience any orthostatic symptoms. Without assistance, he thinks he could not have performed an emergency egress through the side hatch or the overhead hatch, referred to as the Sky Genie, and said the "Sky Genie would have been out of the question. I would have stood up and [after] just [a few] steps would've just fallen over and crashed down."



### 3.2.1.2 Head/body movements provoke motion sickness symptoms

The following are the flight surgeon's notes regarding one crewmember's apparent functioning on landing day:

- Egress movements and removal of Advanced Crew Escape Suit (ACES) provoked neurovestibular symptoms (dizziness)
- Neurovestibular symptoms were exacerbated by head movements.
- General condition: Looked very good. Not sweaty, pale, etc., but dizzy and nauseated with head movements.
- Was not able to [be a subject in postflight science experiments] because of neurovestibular symptoms.
- Remarkable orthostatic stability, seemed to quickly adapt in first hour or so post-landing, but prominent neurovestibular symptoms, with nausea and emesis provoked by head movements and overall movements requiring motor control. Passive [movements] ok.

Furthermore, this crewmember did not do the walk-around (stayed on the Astro-van, or CTV).

On the CTV, coming off the orbiter, this crewmember started doing head movements and got motion sick. According to the flight surgeon, this crewmember will tell you, "I got severely motion sick like I was on a carnival ride." As soon as the CTV started pulling back with that motion this crewmember was vomiting. In fact, the crewmember vomited every time he had to move, even without head movements. This crewmember's flight surgeon was interviewed:

Interviewer: "Now when [the crewmember] was just lying there, could he move his head and get the same symptoms?"

Surgeon: "Lying, not moving, [the crewmember] was fine. I think if you moved [the crewmember] on the gurney, he felt sick. There may have been an orthostatic

component, but [the crewmember] didn't really have any orthostasis ... he felt sick and couldn't even stand. He couldn't do neurovestibular tests, which required a lot of head movements up, down, back and forth."

Surgeon: "[The crewmember] threw up once on the CTV, and then was looking pretty good, and then it was getting him off the CTV, seeing ... family, getting ... into ... room, and he got sick again getting up, and I said 'how about some Meclizine' and he said 'that's a dumb idea, because I'm just going to throw it up.' I gave ... one – he threw it up."

Another crewmember was stunned at the magnitude of symptoms experienced on landing day and found that nothing helped to alleviate them. This crewmember did not premedicate before entry.

A third crewmember's flight surgeon made the following notes on landing day:

Wheelstop+27 min. Sitting up with feet 90 deg down on floor, [the crewmember] notes that pitch and yaw [head] movements [are] OK, but roll is notably provocative.

+33 min. Walking to hatch with assist, turning to hatch to lie backwards

+47 min. Having persistent emesis, still seated in recliner

+56 min. Persistent [neurovestibular symptoms], [the crewmember] was given

Phenergan 50 mg IM; moved off to gurney, starboard side of CTV

A third crewmember noted that 1) not standing motionless; 2) lying, sitting, or walking; and 3) keeping head still [helped] minimize neurovestibular symptoms. He also noted that standing motionless and rapid, unexpected head movements exacerbated symptoms.



A fourth crewmember noted that being prone made landing day symptoms better and added that “being on my back was a piece of cake.” When asked what made his landing day symptoms worse, he responded, “Four months in space. Long duration flight as opposed to a Shuttle mission....Every time I turned my body up I started to get this stomach awareness and...that was what I was...worried about.”

#### 3.2.1.3 Pharmacological treatment of motion sickness

Surgeon: “Phenergan IM 12.5 mg [was] given shortly before... probably helped, and [the crewmember was] able to walk from crew quarters to the suit room [at wheelstop+06:30]. Additional 25 mg [of Phenergan was] given thereafter and [the crewmember] was allowed to sleep for several hours.”

Surgeon: “If I had to do again, I would give someone IM Phenergan and be done with it. I think I gave [the crewmember] a homeopathic 12.5 [mg] IM of Phenergan to try and get [the crewmember] down the hall to sit there and talk. So he did that, and then I gave ... another 25 or 30ish and he slept for a couple of hours until [later] that night. [The crewmember] was feeling better.”

#### 3.2.1.4 Illusory sensations during head movements

Surgeon: “[An onlooker] was looking at [the crewmember’s] face – I was behind him – and [the onlooker] looked at me going (hand motions) meaning [the crewmember’s] gyros were spinning.”

Interviewer: "Did [the crewmember] have any persistent vection illusions? Or pitch-forward illusions?"

Surgeon: "[The crewmember] said very little. Very little."

One crewmember commented:

"I turn my head slightly to the right and down in order to place my helmet on the deck beside me. I immediately feel as if I am doing backward somersaults, spinning tight and fast. I make a mental note not to move my head abruptly and to avoid any further bending or twisting...."

"I turn to the left and start shuffling toward the forward bulkhead with neck braced... At the forward bulkhead I grab on and turn ninety degrees to the left again. Some spinning, but not severe. ... I shuffle to the hatch, bend down on my knees, and after momentarily feeling like I am tumbling again..."

"Because the force of earth's gravity was still very new to me, I felt as though I were spinning and tumbling whenever I moved my head abruptly or leaned forward. These sensations were mildly nauseating."

"... going around any corner provoked the sensation of a delayed tumble ..."

"One by one, people moved in behind my chair to get a picture with [me].... they would inevitably put their hand on the back of the chair which was designed to respond to such pressure by tilting back an inch or two. This slight chair tilt [made me feel like] I was doing a back flip."

In a post-flight interview, a second crewmember described his illusory sensations:

Interviewer: "When you make head movements, are you experiencing any kind of linear translation in the movement, either of yourself or of the visual surround?"



Crewmember: "... I do when I turn..."

Interviewer: "Its rotational?"

Crewmember: "Yes."

Interviewer: "On your motions...do they feel greatly exaggerated with a small head movement?"

Crewmember: "Uh-huh."

Interviewer: "Are there any delays?"

Crewmember: "I have a general lethargy, yeah. Its like ... everything's slow."

Interviewer: "When you do make a head movement, though, do you feel like, for example, the motion as continuing, even though you know that the head movement has stopped."

Crewmember: "I had that a lot yesterday. Don't have it too much today. A little bit."

#### 3.2.1.5 Gaze holding problems

This same crewmember went on to say:

Interviewer: "You felt like you know where the target was pretty much?"

Crewmember: "Yeah, I would find that my concentration was not always [focused]...and my vision would wander..."

Interviewer: "Were you losing the target a lot when it was [not visible]?"

Crewmember: "When it was gone, yeah... I'd find my concentration was not good."

#### 3.2.1.6 Balance and locomotion problems

One crewmember recalled:

“I had a real sensation that if I were to bend forward, if I weren’t careful, I’d continue forward, and if I bent back, if I weren’t careful I’d continue back, and the usual problem of going down a hall, and if you had to make a ... left or right turn, you would tend to overshoot. You’d tend to brush your shoulder on the opposite wall. You just don’t turn sharply enough...”

Scores from the Neurologic Function Exam were recorded for 3 crewmembers on R+0 and only 2 crewmembers on R+3 and are shown in Table 3.3.

<<Table 3.3 should go about here>>

### **3.2.2 Postflight neurovestibular disturbances: R+1 – R+7**

#### 3.2.2.1 Increased sensitivity to g-forces

The sensation of enormous weight continued all day (R+0) for one crewmember. Even later, as he was eating dinner, he’d sit up, eat some food, and then have to go lay down and rest for some minutes before sitting up and trying again. Even lying supine in bed that night, he felt the huge g-force pushing him down into the mattress. But, the next day was better, and by 24 hours post-landing, the subjective strength of gravity had notably abated.

Another crewmember described the experience this way:

“Gravity now yanked me into the mattress.... Getting smashed into the mattress in turn created a sensation of pressure on my body ... [that] would translate into a propulsive force [if I were in space]. It felt ... that I would, at any moment, be thrust out of bed and toward the ceiling.... whenever I would drift off closer to sleep.... [To combat this



feeling], I rolled the sheet into a sort of rope, positioned it firmly across my waist, and tucked the loose ends of the sheet under the mattress. With the sheet now holding me in place as an improvised restraint, ... my mind was put at ease and I relaxed enough to fall asleep.” This crewmember’s head felt heavy when lying on a pillow, and he had a sense of sinking into the bed until R+4.

#### 3.2.2.2 Head/body movements provoke illusions and motion sickness symptoms

A flight surgeon was asked: “How long would you say before [the crewmember] got rid of all neurovestibular [symptoms]...?”

Surgeon: Well, [the crewmember] went back to bed then, and the next morning he got up, was doing better, but still was kind of [woozy]..., had breakfast, ... and ... was still a little nauseated even with walking. Came back up, ... about four hours prior to landing (of the Gulfstream 2 aircraft taking the crewmember back to Ellington), ... I gave [the crewmember] another 25 to 30 mg of Phenergan.... [The crewmember] ... didn’t get sick on the plane, and ... motion sickness began to wane and never came back.

Another crewmember experienced Earth sickness for a day or two. This crewmember said that lying horizontal helped to alleviate landing day symptoms. Rapid head movement, tilting head forward to look at the ground, and rapid turn of the body and/or head made landing day symptoms worse. Nodding and moving the head reportedly made post-flight recovery symptoms worse. He took two 50-mg doses of Meclizine on R+1 at 22:00 and 23:00 in order to alleviate neurovestibular symptoms. Both doses were scored to be “somewhat effective” and made him

feel drowsy. Alcohol consumption was reported to help alleviate neurovestibular symptoms as well. This crewmember had strong translation illusions after head tilt on landing day, which abated over a week. The crewmember provided the following description:

“As on a previous short mission, a classic tilt translation was my dominant vestibular effect upon return. When I tilted my head to the right, I felt I was translating to the left through a distance so large I thought I was in the next room. It was equal in all 4 directions and approximately double the intensity after the extended duration mission as compared with an earlier short mission. The decay of the effect seemed exponential with a time constant of 1 day and therefore the effects were reduced by 98% in 4 days. This ‘decay’ rate was the same for the long and short missions.”

### 3.2.2.3 Balance and locomotion problems

Some of the crewmembers’ balance control performances on computerized posturography tests on R+1 were among the lowest equilibrium scores (i.e. worst) ever recorded in the Neurosciences Lab at JSC [15]. New motor control strategies (co-contraction strategies) seem to emerge early after flight and persist for many days. One crewmember made the following comments:

“On every one of my ... Shuttle flights, on waking up the morning after we landed, I couldn’t even tell I’d been in space, but it was five days before [I felt I had normal balance] after Mir.”

“I jogged three miles, and that’s five days after we landed. It was the hardest three miles I ever did...”



“We heard about people [who had returned from Skylab] that fell in showers or had balance problems.”

A flight surgeon made the following comments regarding a second crewmember:

[The crewmember] was still really wobbly – [the crewmember] looked drunk the first day ... [his] feet would keep slapping the floor. [The crewmember] just couldn't get ... [his] feet up to walk... So ... I had my hand around [the crewmember's] hip for the first day, day and a half. [When the returning crewmember] got off the plane [at Ellington Field in Houston], ... and walked into the house, [the crewmember] was walking unassisted, wobbling some... They landed [from orbit] Thursday evening, this was Friday, and by Monday you really couldn't tell.

A third crewmember noted that rounding corners was hard. He reported that you over-perceive the turn acceleration and flatten out the radius of turn, so you walk wide, and bang into door frames as you go around corners. You feel like a klutz. On R+3, this crewmember reported his level of function to be 40% of normal. This crewmember reported to be cognitively in tune and sharp in flight. Post-flight, cognitive functioning was worse due to distractions caused by neurovestibular effects – it felt like the flu. Further, he felt like his ability to [control advanced body movements], bench press, and walk were 0%, 20%, and 80% of normal, respectively.

### **3.2.3 Postflight neurovestibular disturbances: after R+7**

#### 3.2.3.1 Increased sensitivity to g-forces

“The spray of water from the shower was like pellets bombarding my body. I felt as if I would be sent tumbling.... By the end of the second month of rehab, ... I would shower – no longer feeling as if bullets were riddling my body...”

Another crewmember noted that, even a month after landing, heaviness of limbs and objects was noticeable. This crewmember also responded:

Interviewer: “How long was it after you landed that you felt like you were back to your old self?”

Crewmember: “[I’ve been back] five months now. I’m, I’d say, 80 or 90 percent back.”

#### 3.2.3.2 Postural control and balance disturbances

Compared to short-duration space flight, long-duration crewmembers exhibit greater alterations in sensory-motor function on return to Earth. These changes impact the ability to maintain postural and locomotor control along with compromising the capacity of crewmembers to visually acquire targets leading to extremely delayed responses and visual problems during head and body movements following return to Earth. There appeared to be an initial recovery period of several days as demonstrated by a clinical exam of gross neurologic function. Residual, subclinical neurovestibular impairment was demonstrated in the posture platform, dynamic visual acuity, and gaze stability tests, indicating a slower return to baseline. Full recovery, as measured by the posture platform, took up to 4 weeks. Effects on eye-head coordination seen on long-duration missions (e.g., delayed target acquisition, reduced head velocity following flight, high gain in the visual vestibulo-ocular system, and failure to suppress the vestibulo-ocular



response (VOR) during head/eye target pursuit) were longer lasting for long-duration missions than for short-duration. Recovery, particularly in the pursuit system, was not observed in some crewmembers even 64 days following flight. There is significant alteration in head-trunk coordination during locomotion following long-duration space flight. At least one crewmember showed disruption in lower limb muscle activation patterns during locomotion that exceeds that shown by Shuttle crewmembers. One crewmember said that even at 5 weeks postflight, he was sometimes still “wobbly”. His strength was normal, so he was convinced it was a control problem, and he has not noticed any unusual problems with gait initiation. Finally, at 10 weeks, he was feeling pretty good. Another crewmember had “flutters” of vestibular uncertainty that continued for several months. He did not want to fly [an aerobatic aircraft] solo for two months because he just was not confident.

#### **4. CONCLUSIONS**

##### **4.1 Adaptation to 0-G**

###### **4.1.1 Space Motion Sickness**

- Some crewmembers arrived aboard the relatively small Soyuz vehicle, which limited head and body movements during the first several days in orbit. Once aboard Mir, the large interior volume and the need to move between modules inconsistent visual verticals may make crewmembers more vulnerable to symptoms.
- In one instance, SMS symptoms lasted 10 days for one non-U.S. rookie crewmember.
- One crewmember used Phenergan IV both preflight and in-flight and reported it to be effective in relieving symptoms during the first days of flight.



#### 4.1.2 Spatial orientation

- The larger volume, clutter, and the inconsistency of visual verticals between modules made spatial orientation more difficult. The use of surface color-coding (dark floors, tan walls, and light ceilings) helped provide a local visual vertical within a module. At least one crewmember used colors as orientation references.
- Some crewmembers, including temporary visitors, reportedly had a difficult time navigating through space station modules, especially through the node.
- One crewmember reported he was able to memorize module interiors from an exterior perspective, but was not able to visualize modules from inside others.
- Sense of orientation takes at least a month to become “natural and instinctive” but mental survey is apparently not completely developed even after 3 months in some cases
- In the Mir/Progress docking accidents, the crewmembers’ acknowledged difficulty in maintaining an exocentric coordinate frame might have contributed to their impaired inability to visually locate the incoming Progress.
- One crewmember reported that VRIs (“the downs”) can be cognitively initiated more easily after long-duration exposure to weightlessness.
- One crewmember reported a persistent sense of falling toward the earth throughout an entire EVA. Although not reported in the open literature, several Shuttle EVA crewmembers have anecdotally described similar episodes, so the phenomenon is apparently not unique to long duration flight. While performing EVA, the Earth is often in the lower portion of the visual field, and the station itself may provide only limited visual and proprioceptive orientation cues. EVA training in neutral buoyancy does not simulate the orbital visual environment as submerged astronauts are surrounded by the walls of the pool.



- One crewmember felt that he could induce feelings of falling in any direction (especially backward) with cognitive effort and eyes closed.

## **4.2 Re-adaptation to 1-G**

### **4.2.1 Heaviness and head movements**

- On returning to Earth from long-duration space flight, crewmembers experience many of the same neurovestibular symptoms on landing day as their short-duration counterparts, only frequently with greater intensity and lasting longer periods of time.
- Long-duration crewmembers experienced more pronounced feelings of heaviness during re-entry and several days later postflight than do short-duration crewmembers. On landing day, heaviness is sometimes incapacitating, such that crewmembers do not believe they could egress the orbiter unassisted in the normal way (i.e. through the side hatch). No crewmember believed they could have egressed unassisted through the overhead hatch in an emergency. Subjective heaviness impairs some crewmembers' ability to function normally in everyday activities and can last up to a month after landing.
- Head and body movements can produce nausea during re-entry, and vomiting has been reported. Vomiting can persist for up to several hours post-landing. Sometimes head movements are not necessary to provoke frank emesis. Movement was so provocative postflight that one crewmember could not keep oral anti-nausea medication down.
- Phenergan was used as a countermeasure for mitigating landing day nausea, and at least one crewmember reported it seemed effective.
- At least one crewmember reported that head movements caused persistent illusory spinning and pitching sensations lasting as long as 7 days that impaired standing and walking.

- From 1 week to 2 months post-flight, one crewmember reported that water droplets felt like pellets hitting his body in the shower.

#### **4.2.2 Postural and locomotor control problems**

- Some crewmembers had major difficulty walking after landing. One crewmember reported that running was very difficult 5 days after landing.
- At least 3 crewmembers mentioned that when turning corners they would turn less sharply than intended and sometimes accidentally collide with doorframes.
- There appeared to be an initial recovery period of several days as demonstrated by a clinical exam of gross neurologic function.
- Residual, subclinical neurovestibular impairment was demonstrated in the posture platform, dynamic visual acuity, and gaze stability tests, indicating a slower return to baseline.
- Full recovery, as measured by the posture platform, took up to 4 weeks.
- Some crew members felt like they did not return to baseline until between 10 weeks and 5 months post-flight
- Recovery, particularly in pursuit eye-tracking, was not observed in some crewmembers even 64 days following flight.
- There was significant alteration in head-trunk coordination following long-duration space flight
- At least one crewmember showed disruption in lower limb muscle activation patterns during locomotion that exceeds that shown by Shuttle crewmembers

It is clear that long duration Mir crewmembers experienced neurovestibular dysfunction that was usually more intense and longer in duration than on shorter flights. The differences appear associated to mission duration and vehicle size and architectural complexity. That postflight



disorientation and ataxia increase with mission duration suggests that there are some components of sensory-motor adaptation to weightlessness that occur over timescales far longer than the 1-2 weeks previously assumed by neurovestibular experts [12,13].

Much of the data presented in this paper is anecdotal and the clinical record is incomplete and limits statistical analysis and the level of scientific evidence. Nonetheless, we believe the information obtained is useful to the scientific community and is operationally important. The Institute of Medicine (2001) addressed these problems by noting the need for a more systematic way for collecting clinical data on crewmembers. The committee recommended that NASA “incorporate innovative technologies and practices - including clinical practice guidelines” to produce a more comprehensive set of data related to astronaut health and that research findings be communicated freely to the public. Future data collections need to involve a more quantitative approach to evaluating the health risks of human spaceflight.

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## 7. TABLES

**Table 2.1 Contemporaneously-obtained debrief materials by crewmember**

Crewmember	Flight Surgeon R+0 Notes	Debrief Questionnaire	
		R+0	R+3
A		x	
B			
C	x	x	x
D	x	x	x
E	x		
F	x		
G			

**Table 3.1 Vomiting incidence inflight and postflight**

Crewmember	Vomiting	
	In-flight	Post-flight
A	No	Yes
B	Yes	No
C	No	Yes
D	No	Yes
E	No	No
F	No	Yes
G	Yes	No

**Table 3.2 Readaptation symptom severity scores on R+0**

Symptom Severity Score: 0 = None; 1 = Mild, Symptom awareness; 2 = Moderate, Symptom present, no performance impact; 3 = Severe, Symptom present and interferes with performance

Crewmember Symptom Severity Scores							
On return to 1-G did you experience:	A	B	C	D	E	F	G
Off balance	3	--	1	--	3	--	3
Feel abnormally heavy	3	--	0	--	3	--	3
Problems when making rapid head movements	3	--	3	--	3	--	2
Clumsiness	3	--	1	--	1	--	2
Dizziness	3	--	0	--	1	--	--
Difficulty turning corners	3	--	2	--	2	--	2
Motion illusions – spinning	3	--	0	--	1	--	1
Motion illusions – pitching	3	--	3	--	2	--	0
Motion illusions – other	3	--	0	--	3	--	0
Sweating	0	--	0	--	0	--	1

Nausea	0	--	1	--	1	--	1
Stomach awareness	0	--	1	--	1	--	1
Malaise/sluggishness	0	--	0	--	0	--	0
Disorientation	3	--	0	--	0	--	0
Vomiting	0	--	2	--	0	--	0
Dry heaves	0	--	0	--	0	--	0
Other	0	--	0	--	0	--	0

**Table 3.3 Neurologic Function Rating scores on R+0 and R+3**

Scoring convention: 1 = None; 2 = Mild; Occasional (does not interfere with activity); 3 = Moderate; Frequent (interferes with some activity); 4 = Severe; Persistent (interferes with most activity)

Category	Item	Crewmember													
		A		B		C		D		E		F		G	
		R+0	R+3	R+0	R+3	R+0	R+3	R+0	R+3	R+0	R+3	R+0	R+3	R+0	R+3
Symptom	Headache	--	--	1	1	--	--	1	--	--	--	1	1	--	--
	Dizziness/ Faintness	--	--	1	1	--	--	3	--	--	--	3	1	--	--
	Vertigo/ Spinning	--	--	3	1	--	--	4	--	--	--	3	1	--	--
	Gaze/ Ocular	--	--	2	1	--	--	2	--	--	--	1	1	--	--
Motor Perform.	Finger to nose	--	--	2	2	--	--	2	--	--	--	1	1	--	--
	Drift	--	--	Not done	1	--	--	Not done	--	--	--	1	1	--	--
	Rising From chair	--	--	Not done	Not done	--	--	2	--	--	--	Not done	1	--	--
Gait and Station	Standing/ Romberg	--	--	Not done	2	--	--	Not done	--	--	--	Not done	1	--	--
	Leg lift - Hop	--	--	Not done	Not done	--	--	Not done	--	--	--	Not done	4	--	--
	Tandem/ Heel-to-toe walk	--	--	Not done	2	--	--	Not done	--	--	--	Not done	2	--	--
	Dynamic equilibrium	--	--	Not done	2	--	--	Not done	--	--	--	Not done	4	--	--
	Total	--	--			--	--		--	--	--		18	--	--